

Assessment of Sulfur Status and its forms in Soils of the NOUN Research Farm, Rigachikun, Kaduna State, Nigeria

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ABSTRACT

A study was conducted to evaluate the status and forms of Sulphur in soils of Rigachikun, Kaduna State, Nigeria, as part of the National Open University of Nigeria (NOUN) research initiative. Soil samples were systematically collected using a grid sampling method across the farming community in Rigachikun, with 297 samples taken at a 0–30 cm depth. The samples underwent standard soil testing, and Sulphur forms were analyzed using the turbidimetric method. Data interpretation was conducted using descriptive analysis. Results indicated that Rigachikun soils predominantly consisted of sandy loam with a slightly acidic to neutral pH, low organic matter content (0.38%), and nitrogen level (0.06%). Sulphur content in Rigachikun soils was within sufficient range, with notable differences in the concentration of Sulphur forms. Total Sulphur had the highest concentration at 498.30 mg kg⁻¹, while non-sulphate Sulphur recorded the lowest at 0.74 mg kg⁻¹. The observed low levels of adsorbed and non-sulphate Sulphur were associated with the sandy loam texture and pH range of 6.24 to 6.99. In conclusion, the Sulphur status in Rigachikun soils is adequate. Therefore, it is recommended that management practices promoting Sulphur mineralization should be adopted by farmers to optimize sulphate availability for crop productivity.

INTRODUCTION

Sulphur (S) is a crucial macronutrient for plant growth and crop productivity. It is ranked as the fourth major essential nutrient and plays an essential role in both primary and secondary plant metabolism (Glowacka, 2016). Sulphur is involved in several vital plant functions, including protein synthesis, conversion of inorganic nitrogen (N) into protein, chlorophyll production, nodule formation in legumes, and the creation of enzymes. Additionally, Sulphur is a structural component in compounds responsible for the characteristic flavors and aromas of plants like mustard, Onion, and Garlic (Sutar et al., 2017). Sulphur is present in soils in organic and inorganic forms, such as elemental S, water-soluble S, and adsorbed forms, but plants can only absorb it in its mineralized inorganic form, specifically as sulfate (SO₄-S).

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In agricultural soils, the inorganic Sulphur content is largely determined by soil properties like texture, pH, Organic Matter, and drainage. In well-drained soils, Sulphur mainly exists as sulfate ions, either water-soluble or adsorbed onto soil particles, and becomes plant-available following mineralization processes (Bappa et al., 2017). However, continuous cultivation, particularly of high-yielding varieties, often results in significant S depletion, particularly in areas where S-containing fertilizers are rarely applied.

In Northern Nigeria, particularly in areas such as Rigachikun, Kaduna, sulfur deficiencies have become an increasing concern. The main crops cultivated in the region include cereals (like sorghum and millet), legumes (such as cowpea), and vegetables. Cereals generally have a lower sulfur requirement (around 3-4 kg per ton of seed)

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compared to oilseeds and legumes, yet the high productivity of cereals increases sulfur uptake per unit area (Safaa et al., 2013). Furthermore, the rapid adoption of high-yielding varieties of crops like maize has exacerbated sulfur depletion in soils, particularly when crop residues are removed from the field, thereby reducing the available S supply from the soil profile (Xue et al., 2012).

Although several soil studies have been conducted in Northern Nigeria, including in Rigachikun, Kaduna (Amin et al., 2022; Almu et al., 2021), there remains limited information on sulfur levels and forms in the soils of these locations. Considering sulfur's critical role in various plant processes and its synergistic relationship with nitrogen and phosphorus nutrition, sulfur deficiency can severely impact crop productivity by limiting nutrient uptake. This study, therefore, aims to assess the status and forms of sulfur in the soils of Rigachikun, Kaduna, and contribute to strategies for enhancing crop yield by addressing potential sulfur deficiencies in the area.

MATERIALS AND METHODS

Study Area

The study was conducted in Rigachikun, located within Igabi Local Government Area (LGA) of Kaduna State, Nigeria. Rigachikun is situated northeast of Kaduna city and bordered by Chikun and Giwa LGAs. It lies within latitudes 10°34'N and 10°39'N and longitudes 7°26'E and 7°30'E, covering an approximate area of 340 km². The region is characterized by a savannah ecosystem with distinct wet and dry seasons. The wet season occurs from May to October, while the dry season extends from November to April. The area receives an annual rainfall of 900–1000 mm, with temperatures ranging from 15°C to 35°C.

The geology of Rigachikun includes sedimentary formations, with soils predominantly classified as Alfisols, Entisols, and Inceptisols. The soils in this area are known for being well-drained and moderately fertile, supporting a variety of agricultural activities, particularly cereal-based cropping systems.

Soil Sampling and Collection

Soil samples were collected from 200 intensively cultivated, cereal-based farmlands using a systematic grid sampling method in the Rigachikun area. A 300m-by-300m grid was overlaid on each farm, and sampling points were identified at the center of each grid. Soil samples were taken from a depth of 0–30 cm at each sampling point, ensuring consistency across all sites. A total of 200 soil samples were collected. The soil samples were transported to the laboratory, where they were air-dried, gently crushed, and passed through a 2mm sieve. Each sample was then stored in air-tight containers for subsequent chemical and physical analyses.

Laboratory Analysis

Soil texture was determined using the Bouyoucos hydrometer method, following the protocol described by Gee and Bauder (1986). Soil pH was measured using the procedure outlined by IITA (1982). A Jenway 3520 glass electrode pH meter was used for this purpose. Organic carbon content in soil was measured using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen (N) was determined through the micro-Kjeldahl digestion method as described by Bremner (1996). For soil samples with pH below 7, available phosphorus (P) was determined using the Bray 1 method (Bray and Kurtz, 1945). In samples with pH above 7, the Olsen method was applied (Olsen, 1950).

Exchangeable cations were extracted using a 1N NH₄OAc solution buffered at pH 7.0, as per Anderson and Ingram (1998). The concentrations of potassium (K) and sodium (Na) were measured using a flame photometer, while calcium (Ca) and magnesium (Mg) concentrations were determined using an atomic absorption spectrophotometer. Exchangeable acidity was determined by extracting with 1N KCl and titrating with 0.05N NaOH, according to Maclean (1965). Available sulphur in soil was measured using the turbidimetric method as described by Chesnin and Yien (1950). Sulphate sulphur was extracted using a 0.15% CaCl₂ solution (Williams and Steinbergs, 1959). Adsorbed sulphate was analyzed by subtracting the sulphate values obtained from the

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CaCl_2 extractant from those obtained using a KH_2PO_4 extractant (Fox et al., 1964). Organic Sulphur was calculated by subtracting the amount of Sulphur extracted with 0.01M KH_2PO_4 from the total Sulphur content (Evans and Rost, 1945). Total Sulphur was determined using a diacid digestion procedure as per Chapman and Pratt (1961). Non-sulphate Sulphur was calculated by subtracting the sum of organic and inorganic Sulphur from the total Sulphur (Virmani and Kanwar, 1971). All Sulphur contents from the various extracts were measured using the turbidimetric method (Chesnin and Yien, 1951).

Data Analysis

Descriptive statistics were employed to summarize data generated from routine analyses. An analysis of variance (ANOVA) was conducted to evaluate the different forms of sulfur present, and significant differences in mean values were determined using Tukey's Honest Significant Difference (HSD) test at a 5% significance level. All statistical analyses were performed using Genstat version 17.0.

RESULTS AND DISCUSSION

Physical and Chemical Properties of Soils at NOUN Research Site, Rigachikun, Kaduna

This study examined the physical and chemical properties of soil samples collected from the NOUN research site in Rigachikun, Kaduna. The results are presented in Tables 1 and 2. The soil particle size analysis indicated that most sampling points classified as sandy loam. The prevalence of sandy fractions across the site likely reflects the parent materials, predominantly derived from Precambrian basement complex rocks, such as granitic sandstones, as described by Shehu et al. (2015). According to Malgwi et al. (2000), this high sand content can result from clay eluviation and wind erosion, processes commonly observed in the soils of northern Nigeria. The sandy texture notably affects the soil's water-holding capacity and nutrient retention abilities.

The mean soil pH (measured in water) at the Rigachikun site was recorded as 6.52, which categorizes the soil as slightly acidic. This mildly acidic environment supports a variety of

crops and reflects management practices aligned with recommended pH levels for sustainable agriculture (Brady and Weil, 2002). Like neighboring farming communities, Rigachikun employs diverse cropping systems, incorporating cereals and legumes, which help maintain soil pH balance. Organic carbon content, a crucial component of soil health, was low, averaging 0.30%. The low organic carbon levels may be attributed to minimal vegetation cover and the common practice of complete crop residue removal post-harvest. Shehu et al. (2015) indicated that poor land cover and unsustainable practices contribute to organic matter depletion, diminishing soil productivity over time.

The average sulfur content in the Rigachikun soils was 0.12%, ranging from 0.06% to 0.18%, which is above the critical threshold for Nigerian savanna soils (0.06% as defined by Esu, 1991). This level indicates sufficient sulfur, possibly resulting from the prevalent cereal-legume systems, which require less sulfur than high-yield or oilseed crops. The mean available phosphorus content at Rigachikun was 7.25%, rated as low to moderate. The exchangeable potassium levels, averaging 0.10 cmol kg^{-1} , were also low. Potassium distribution varied across the site, suggesting that potassium-rich areas could support crops with high potassium requirements, such as certain tree crops, while other areas may benefit from potassium amendments.

The average exchangeable calcium and magnesium values were 0.89 and 0.24 cmol kg^{-1} , respectively, both rated as low. Sodium was rated as moderate, at 0.20 cmol kg^{-1} , indicating that the site may benefit from targeted lime and magnesium applications to enhance nutrient levels for optimal crop performance. Available iron levels at Rigachikun ranged from 5.10 to 62.10 mg kg^{-1} , with an average of 24.25 mg kg^{-1} , sufficient to meet crop requirements. However, other micronutrient deficiencies were observed, suggesting a need for additional micronutrient supplementation to maintain soil fertility. The overall low cation exchange capacity (CEC), combined with low organic carbon and total nitrogen, is characteristic of soils with minimal weatherable minerals, likely due to their aeolian

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origin (Manu et al., 1991). This highlights the need for integrated soil fertility management, including organic matter additions and nutrient cycling practices, to improve productivity.

In summary, the NOUN research farm at Rigachikun displays several soil characteristics typical of the Nigerian savanna. The sandy loam texture, low organic carbon, slightly acidic pH, and

moderate sulfur levels indicate that while the soil can support certain cropping systems, specific amendments and sustainable practices are essential to ensure long-term soil health and productivity.

Table 1: Physiochemical properties of soils in Birnin Yero

Soil parameter	Mean	Min	Max	CV
Sand (%)	76.47	73.80	78.00	1.14
Silt (%)	12.11	6.24	19.69	20.97
Clay (%)	11.41	5.14	16.22	16.54
pH (1:1)	6.99	4.54	8.90	15.73
Nitrogen (%)	0.06	0.00	0.39	69.44
Organic C (%)	0.38	0.09	1.97	56.12
Sulphur (%)	0.14	0.04	0.66	50.88
P (mgkg ⁻¹)	12.50	0.52	51.34	94.55
K (cmolk ⁻¹)	0.14	0.00	7.07	394.63
Ca (cmolk ⁻¹)	1.13	0.05	8.47	95.58
Na (cmolk ⁻¹)	0.44	0.01	8.37	154.66
Mg (cmolk ⁻¹)	0.54	0.00	5.89	136.25
Fe (mgkg ⁻¹)	83.13	0.01	101.30	106.25
Zn (mgkg ⁻¹)	2.75	0.012	128.50	342.61
Cu (mgkg ⁻¹)	2.24	0.048	5.32	42.14
Mn (mgkg ⁻¹)	0.14	0.002	3.58	213.83

Table 2: Physical and chemical properties of soils in Rigachikun

Soil parameter	Mean	Min	Max	CV
Sand (%)	75.10	74.50	75.70	0.35
Silt (%)	16.29	7.89	20.33	17.16
Clay (%)	8.59	4.93	17.22	31.79
pH (1:1)	6.24	4.44	8.11	14.68
Nitrogen (%)	0.03	0.02	0.05	22.63
Organic C (%)	0.24	0.16	0.30	15.60
Sulphur (%)	0.09	0.07	0.11	13.36
P (mgkg ⁻¹)	5.98	0.94	11.92	55.23
K (cmolk ⁻¹)	0.08	0.01	0.38	113.36
Ca (cmolk ⁻¹)	0.94	0.09	5.47	116.14
Na (cmolk ⁻¹)	0.19	0.03	0.33	42.85
Mg (cmolk ⁻¹)	0.21	0.02	1.31	119.42
Fe (mgkg ⁻¹)	21.55	4.50	59.72	58.53
Zn (mgkg ⁻¹)	1.62	0.084	11.59	145.14
Cu (mgkg ⁻¹)	2.42	0.446	4.19	38.24
Mn (mgkg ⁻¹)	2.58	0.221	17.46	122.29

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Forms of Sulfur

The study conducted at Rigachikun, Kaduna, evaluated various forms of sulfur across two farming communities. The experiment showed that total sulfur (Total S), encompassing all sulfur forms in the soil, had the highest concentrations, with values of 429.20 mg/kg and 412.41 mg/kg in the two locations (see Table 3). This elevated total sulfur content can be attributed to the initially sufficient sulfur levels observed during the physicochemical analysis. Organic sulfur emerged as the dominant contributor to total sulfur.

Notably, the Birnin Yero location, characterized by substantial shrubland that remains uncultivated, exhibited higher total sulfur. This undisturbed shrubland likely preserved the soil's natural fertility, contributing to its elevated total sulfur content. However, Birnin Yero also displayed low to moderate organic carbon levels

(see Table 1), indicating that both past organic matter from crop residues and the presence of shrubland contributed to the organic sulfur levels. In terms of inorganic sulfur, Birnin Yero contained 36.36 mg/kg, while sulfate sulfur reached 35.15 mg/kg (Table 3). These values may be due to the slow decomposition of organic residues in the shrubland. By contrast, Rigachikun had slightly higher inorganic sulfur at 37.56 mg/kg and sulfate sulfur at 36.67 mg/kg, likely due to faster mineralization processes in its soils.

Non-sulfate sulfur levels were low in both locations, with values of 0.851 mg/kg in Rigachikun and 0.580 mg/kg in Birnin Yero (Table 3). This low level aligns with the soils' low salt content, which restricts the formation of non-extractable sulfur compounds. Additionally, both fields exhibited a decline in adsorbed sulfate, likely influenced by the soil's pH and sandy texture.

Table 3: Non-sulfate sulfur levels

Soil sample	Total S	Inorganic S	Sulphate S (mgkg ⁻¹)	Organic S	Non-sulphate S	Adsorbed S
Birnin Yero	429.20	36.36	35.15	393.50	0.58	1.22
SE	13.89	2.61	0.99	13.17	0.20	0.50
Rigachikun	412.41	37.56	36.67	374.90	0.851	0.891
SE	3.000	0.297	0.211	2.740	0.041	0.042

CONCLUSION AND RECOMMENDATION

The results obtained from the present investigation indicate that the soil from both locations possesses sufficient levels of Sulphur, with Birnin Yero having 0.14% and Rigachikun 0.09%. This sufficiency is attributed to the cultivation of crops with low Sulphur requirements. However, the study revealed that the levels of total Sulphur, organic Sulphur, inorganic Sulphur, and sulphate Sulphur were notably high. Therefore, it is recommended that management strategies be implemented to enhance the mineralization of Sulphur in the soil. These strategies should include the recycling of crop residues, the addition of organic matter, and the application of Sulphur fertilizers at the appropriate locations, times, and in suitable quantities. Such practices will help

maintain sulphate availability in the soil and contribute to improved agricultural productivity.

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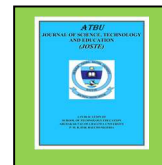
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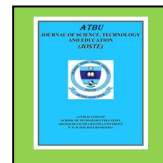
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